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Winter Operations, Abrasives and Salt Brine

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WINTER OPERATIONS

ABRASIVES AND SALT BRINE

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16. Abstract

The primary objective of winter maintenance operations is to improve traffic safety and efficiency during winter storm periods. Abrasives and salt brines have been successfully applied to increase traction and prevent snow and ice from bonding to road surface. However, because of some undesired side effects, such as corrosion and damage to the environment, salt and abrasives may need to be supplemented by other substances in some areas. Powerful non-corrosive acetate-based chemicals have been considered by several agencies, but their high price has limited their use. Recent research has focused on the use of new, less corrosive, and highly effective chemicals, such as liquid corn salt (LCS). This research project evaluates and compares the cost-effectiveness of using salt brine, and LCS on Nebraska highways. Field studies were conducted during the winter of 2002-2003 on two highway sections in Nebraska. Available field data included weather information, chemical use, time to achieve bare pavement, and maintenance log records. A benefit-cost analysis was performed to determine the cost-effectiveness of each treatment alternative. The operational benefits were the savings in road user costs resulting from reduction in travel time and delay. They were determined from field study data. The safety benefits related to accident reduction due to improved road surface conditions were not considered because of lack of accident data on LCS-treated roadways. The costs included material, labor and equipment costs. Material costs were determined from material usage data obtained from maintenance logs. Labor and equipment costs were estimated from relevant literature. The cost-effectiveness of salt brine and LCS were compared based on their benefit-cost ratios calculated over a range of ADTs and truck percentages. Guidelines were developed for the most appropriate use of these chemicals under various weather and traffic conditions.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Winter weather often creates hazardous driving conditions, which contribute to increases in the frequency and severity of highway crashes. Effective snow and ice control is a vital service to ensure that road users can travel safely, and with minimum disruption even under severe winter weather condition. Maintenance crews of the Nebraska Department of Roads (NDOR) use different treatment options in their winter operation for both de-icing and anti-icing. For de-icing, typically salt brine or salt and sand mixture is applied after or during storms to break the bond between the pavement and the ice or frozen snow. For anti-icing, primarily salt brine is applied before winter storms to prevent ice and snow from bonding to the pavement.

Salt is used as snow- and ice-control material in many states. It can be applied to roadway surface in solid, liquid (salt brine), and prewetted form. The most widely used salt is sodium chloride (NaCl), which is fairly inexpensive and can melt snow and ice at temperatures as low as -6 ^{o}F. However, below 14 ^{o}F, the quantity of salt required rapidly increases, which makes it both economically and environmentally undesirable. Fonnesbech (*1*) considers dry salt useless for anti-icing when the road surface is dry and clean, because without moisture, salt particles are likely to be blown off the road before having any effect. Dry salt was found ineffective even below the relative humidity of 80 percent (*2*). By prewetting salt, adhesion to pavement can be increased, and more salt will remain on the roadway surface, especially under dry conditions. As reported by Batchelor (*3*), the enhanced residual effect of prewetting could reduce the amount of salt by up to 50 percent in some areas. The effectiveness of treatment can be further improved by using salt brine. Salt brine is more evenly distributed, and stays longer on the road surface. An experiment conducted in Denmark (*1*) showed 26-percent salt savings associated with the use of salt brine, in contrast to prewetting.

Abrasives are used only when salt is ineffective, or an increase of friction is needed to maintain traffic safety. The main deficiency of abrasives is the short duration of their effectiveness. According to Dahlen and Vaa (4), dry sand applications become ineffective after the passage of 50 vehicles. Another negative effect of using abrasives is that gravel or soil remaining on the road shoulders after treatment is expensive to remove (*1*).

Conventional winter maintenance using salt and abrasives usually works well as long as snow packed or icy roadway surface does not develop. However, during periods of high traffic demands and severe weather conditions this conventional practice may not be effective, and the costs of maintenance may become unreasonably high. In addition to increased costs, excessive salt and abrasive applications may have adverse corrosive effect on vehicles, bridge- and road structures, and on the environment. Less-corrosive acetate-based chemicals, such as calcium magnesium acetate (CMA), have been considered by several agencies, but their high price has limited their use. The price of CMA is about $650 per ton, and it is often less effective than salt (*9*).

To make their winter maintenance operation more cost-effective, NDOR districts are interested in the exploration of new chemicals with higher efficiency in melting snow and ice as well as less impact to the environment.

1.2 OBJECTIVE

One purpose of this study was to review the current practice and materials used by NDOR maintenance crews in their winter operation, and identify alternative treatment options. The primary objective was to evaluate the cost-effectiveness of the most promising treatment alternatives, and develop guidelines for their use under various traffic and weather conditions.

1.3 CONTENTS OF REPORT

The procedure, findings, conclusions and recommendations of the research are presented in this report. The survey of the current winter operation practice of NDOR districts is presented in Chapter 2. Field evaluations of two selected treatment options, using salt brine and liquid corn salt (LCS), are described in Chapter 3. A benefit cost-analysis of these two treatment options is discussed in Chapter 4. Guidelines developed for the cost-effective application of salt brine and LCS, are described in Chapter 5. The conclusions and recommendations of the research are presented in Chapter 6.

Chapter 2

CURRENT PRACTICE

A survey was conducted to review current winter maintenance practice in Nebraska. A questionnaire was circulated among maintenance crew managers of all eight districts of NDOR. Information was collected on treated roadways, material usage, and the decision-making process related to the winter operation practice at all districts. A copy of the questionnaire is shown in Appendix A, and the survey results are discussed in this chapter.

A distribution of treated lane-miles according to various roadway types is shown in Table 2.1. Nearly 84 percent of the total length of roadways (31,697 lane-miles) covered by winter maintenance is rural highway. Approximately 15 percent of the treated lane miles are on interstate highways or expressways. Urban streets represent only a very small fraction, less than 2 percent, of the total lengths of treated roadways.

Table 2.1 Roadway Types and Lengths Covered by Winter Maintenance

Roadway Types	Length (lane-miles)	Percentage (%)
Rural Highway	26,595	83.91
Interstate Highway	2,419	7.63
Expressway	2,055	6.48
Urban Streets	628	1.98
Total	31,697	100

During severe winter weather conditions, maintenance crews regularly check the highways, and apply some sort of treatment to remove snow and ice, or prevent its formation. Maintenance activities typically involve a combination of four actions: (1) road check, (2) application of abrasives and plowing, (3) anti-icing, and (4) deicing. A part of the survey gathered information on how frequently these actions are performed by maintenance crews across Nebraska. Possible responses included: “NOT AT ALL”, “MINIMALLY”, “MODERATELY”, and

“EXTENSIVELY”. Accordingly, responses were coded from “1” (NOT AT ALL) to “4” (EXTENSIVELY) for the purpose of a quantitative analysis of the results. The reported frequency levels for the four maintenance actions are summarized in Table 2.2.

Table 2.2 Frequency Levels of Maintenance Crew Actions

Maintenance Crew Actions	# Responses	Average Rating	Range		Standard Deviation
			Low	High	
Road Check	81	3.81	2	4	0.4997
Application of Abrasives and Plowing	81	3.83	3	4	0.3781
Anti-icing	78	2.31	1	4	0.8960
Deicing	81	3.33	1	4	0.8889

Values in the third column, labeled “Average Rating” are indicative of the average usage of the four maintenance actions across Nebraska. Higher values on a 1-4 scale correspond to higher frequencies. For example, “Road Check” is performed as frequently as the “Application of Abrasives and Plowing” on average. The rating of over 3.8 indicates that both actions were quite extensively used. The average rating for deicing is 3.33, indicating that the frequency of deicing was between moderate and extensive. Anti-icing rated at 2.3 is the least frequently used maintenance action. The values in the last three columns account for the variation within the winter maintenance practices of various districts and maintenance crews. The codes in columns “Low” and “High” correspond to the lowest and highest frequencies reported by all maintenance crews. The range (i.e., High-Low) for “Road Check” and “Application of Abrasives and Plowing” is much narrower than the range for “Anti-icing” and “Deicing”, which suggests that the most significant differences between districts and maintenance crews are in their anti-icing and deicing operations. The standard deviations reported in the last column indicate similar tendencies.

Information on material usage was also gathered. It was found that application of abrasives, to increase pavement friction, is the most commonly used treatment option across the state. Sodium chloride or calcium chloride, in either solid or solution format, was also added to the abrasives to avoid caking. If salt was added as solution, it was done in relatively small amount.

The choices of liquid chemicals for prewetting abrasives are shown in Table 2.3. Note that three crew managers also reported the use of 100 percent dry salt for anti-icing and deicing.

Table 2.3 Liquid Chemicals Used For Prewetting

Chemical	NaCl	$CaCl_2$	$MgCl_2$	M1000	M2000	LCS
Percentage of maintenance crews using chemical (%)	45.7	14.8	1.2	13.6	34.6	0

Liquid chemicals have also been tested on several experimental highway sections. These liquid chemicals included sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), caliber M1000, caliber M2000 and liquid corn salt (LCS). Table 2.4 shows the percent of maintenance crews using each of the liquid chemicals.

Table 2.4 Liquid Chemical Usage by Maintenance Crews

Chemical	NaCl	$CaCl_2$	$MgCl_2$	KAc	M1000	M2000	LCS
Percentage of maintenance crews using chemical (%)	67.9	44.4	1.2	0	46.9	7.4	6.2

Sodium chloride is the most frequently used chemical because it is capable of melting snow and ice under normal winter conditions (i.e., when pavement temperature is higher than 23 ^oF), and the price of its diluted solution for application is only \$0.05 per gallon. Calcium chloride, used as prewetting chemical, is also fairly popular. It was chosen for prewetting because the less expensive sodium chloride becomes ineffective at temperatures below 15 ^oF, when abrasives are also often applied to increase pavement friction. Two other chemicals that need to be mentioned are caliber M1000 and LCS. Both of them are corn-based deicing and anti-icing products (*8*). The price of caliber M1000 is \$0.60 per gallon, and the price of LCS is \$0.20 per gallon. Winter maintenance experience in NDOR District 3 indicates that the effect of LCS lasted longer than that of caliber M1000 under the same weather and traffic conditions. Because of its higher effectiveness, fewer applications of LCS are needed, which in turn can reduce maintenance costs. The percentage of crews using LCS is relative low (6.2 %) because it is still in its experimental phase, and has been tested only in NDOR District 3.

The survey also acquired information on the maintenance supervisors' decision-making process with regard to their winter operation decisions. Newspapers, radio, television, internet, and road weather information system (RWIS) were reported as information sources. The main information types considered by maintenance crew managers included short- and long-term weather forecasts, road and traffic conditions, and observations from road checks. The percentages of maintenance crew managers considering these information sources are given in Table 2.5. Nearly all crew managers used weather forecasts and road condition data, and observations from road checks in their winter operation decisions. However, only 60 percent of them reported the use of traffic information (e.g., increased traffic demand during local events) in their decision process.

Table 2.5 Information Considered by Maintenance Crew Managers

Information	Percent considering the information
Long-term Weather Forecast	95 %
Short-term Weather Forecast	80 %
Road Conditions	99 %
Traffic Conditions	60 %
Observations from Road Checks	96 %

Pavement conditions such as temperature, moisture, and concentration of chemicals are critical to the success of winter operations. Besides highway inspections, Road Weather Information Systems (RWIS) are often used to provide real-time surface conditions. The percent of crew managers obtaining weather information from RWIS is summarized in Table 2.6.

Table 2.6 Percent of crew managers obtaining weather information from RWIS

Information available from RWIS	Percent having access to information
Pavement temperature	75 %
Pavement condition (wet or dry)	80 %
Concentration of chemicals left	23 %
Air temperature	9 %
Wind speed and direction	14 %
Dew point	1 %
Precipitation	1 %

Chapter 3

FIELD EVALUATIONS OF SELECTED TREATMENT OPTIONS

3.1 Treatment alternatives

Maintenance crews may choose to apply dry or prewetted solid materials, and liquid chemicals in their winter maintenance operations. These materials differ in their costs and effectiveness. Based on past winter operation experience, it is reasonable for NDOR to choose liquid chemicals for preventive anti-icing purposes during normal winter precipitations, and supplement it with abrasives for emergency applications when conditions do not allow liquid chemicals to work effectively. In this study, two liquid chemicals, salt brine (i.e., solutions of sodium chloride) and liquid corn salt were considered. These two materials were field tested to evaluate their cost-effectiveness, and to develop guidelines for their most appropriate use.

3.2 Field Studies

Field studies were conducted on two highway sections near Norfolk, Nebraska. The study area is shown in Figure 3.1. An 18-mile section (36 lane-miles) on Highway 275, and a 24-mile section (96 lane-miles) on Highway 81 were treated with salt brine and LCS during major snow events over the winter of 2002-2003. Because of the fairly mild weather conditions during the winter of 2002-03, there were very few events with significant snow accumulation. From these events, there was only one occasion when the two roadway sections were simultaneously treated with different materials. Highway 275 was treated with salt brine, and Highway 81 with LCS. The snow accumulation, temperature variation, and treatment schedule during the period of January 15 through 16 is shown in Figure 3.2.

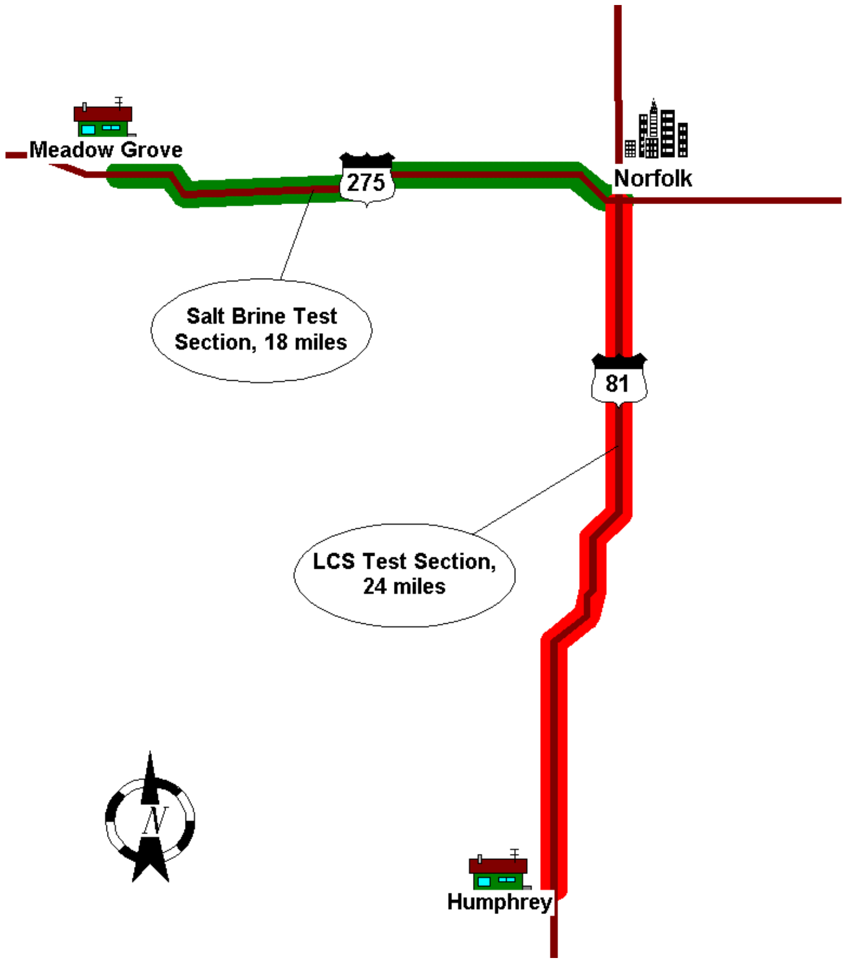


Figure 3.1: Study Area

The temperature remained below freezing during almost the entire study period. In total, 21,000 gallon of salt brine and 21,900 gallons of LCS was applied during four days, as indicated on Figure 3.2. However, an analysis of the hourly data available for weather and pavement conditions indicated that 16,600 gallons of LCS, applied during the first two days, have been enough to achieve snow- and ice-free pavement. Therefore, subsequent LCS applications over the last two days of the study period were not considered in the benefit-cost analysis discussed in the following chapter.

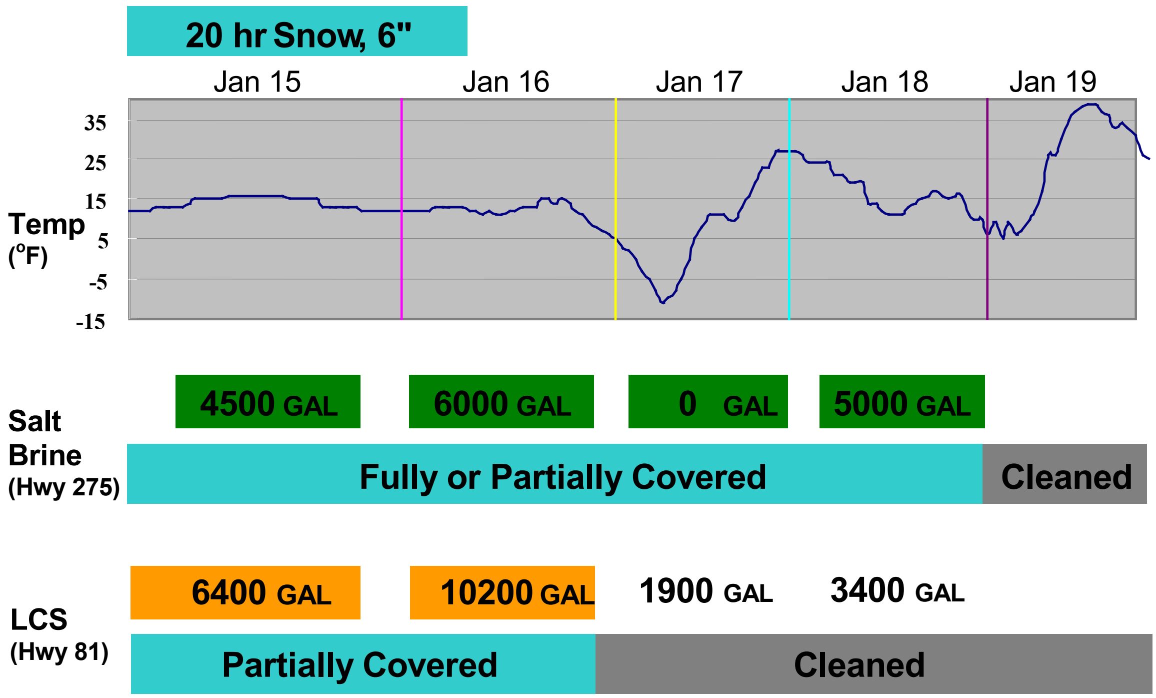


Figure 3.2: Treatments and Results

Chapter 4

BENEFIT-COST ANALYSIS

A benefit-cost analysis was performed to assess the cost-effectiveness of using salt brine and LCS during the snow event of January 15 through 16. The two materials were compared based on the ratio of their estimated benefits generated from snow removal and their associated costs. Both benefits and costs were quantified in monetary terms as described in the following section.

4.1 Benefits

Snow and ice removal during highway winter maintenance has both safety, and operational benefits. The safety benefits are associated with accident reduction due to safer driving conditions on snow and ice-free pavement. Operational benefits are associated with cost savings by road users experiencing shorter delays due to improved traffic operation after snow removal. Since LCS is a fairly new material in winter operations, accident records associated to its use are not available. Therefore its safety benefits cannot be reliably estimated, and were not included in the benefit-cost analysis. Benefits used in this analysis were the expected road user cost savings provided by highway winter maintenance relative to snow and ice-covered roadway conditions. The main components of road user costs are traffic delay costs and increased fuel costs.

Travel delays are consequences of speed reductions on snow and ice-covered roadways. A previous study (*6*) indicated that the reductions in average travel speeds due to icy road conditions are about 25 percent on two-lane highways, and 17 percent on freeways. These figures are based on the American Association of State Highway and Transportation Officials (AASHTO) user benefit analysis methodology. For this study a 17 percent speed reduction was assumed for both highway sections.

The values of travel time used in the analysis were taken from the AASHTO publication *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (7)*. These values were updated to 2002 values using consumer price indices as described in the manual. The updated values are shown in Table 4.1.

TABLE 4.1 Values of Time (*7*)

Vehicle Type	2002 Value
Passenger Car[a]	\$11.11/hr
Single Unit Truck	\$20.40/hr
Tractor-Trailer Truck	\$23.32/hr

[a] Average value for all trip purposes, average vehicle occupancy of 1.56 persons.

The expected travel cost savings (TCS) accrued from the removal of snow and ice can be computed as:

$$TCS = NS\left(\frac{L}{V(1-r)} - \frac{L}{V}\right)$$

where:

TCS = total travel cost savings in one period of winter event (\$);

N = total number of vehicles passed through maintenance area during the time period with clean road surface (estimated from 2002 ADT);

L = one-direction length of highway under the coverage of maintenance (miles);

V = posted speed of maintenance area (mph);

r = assumed travel speed reduction (%/100); and

S = value of travel time per vehicle in 2002 (\$/hr).

4.2 Costs

Highway winter maintenance costs include material, equipment and labor costs. The unit price of material is $0.05/gallon for salt brine and $0.20/gallon for LCS. The cost of material used during the snow event of January 15 through 16 is shown in Table 4.2.

TABLE 4.2 Material Costs

Liquid Chemicals	Unit Price	Quantity	Cost
Salt Brine	$0.05/gallon	21,000 gallon	$1,050
Liquid Corn Salt	$0.20/gallon	16,600 gallon	$3,320

Equipment and labor costs were estimated from the total time of application during the four-day event. Based on a previous study (*8*) labor costs were estimated as $ 28.14/hour per person and equipment costs are estimated as $26.49/hour for both salt brine and LCS applications.

4.3 Results

Details on the applications of salt brine and LCS during the field study are shown in Table 4.3. Note that the actual and effective application amounts (gal) of LCS are different. It is because the first two days of LCS-treatment was sufficient to clear the pavement from ice and snow. Although treatment continued for the remaining two days of the study period, LCS was mostly applied to already clean pavement during this time. Using the total amount of LCS actually applied during the four-day period would probably underestimate the cost - effectiveness of this material, because there was no significant precipitation during the last two days. Therefore, the benefit-cost calculations for LCS were performed in two different ways: first using the total amount actually applied during the four day period, and then using only the effective amount needed to achieve clean pavement within the first two days. The benefit-cost calculations for salt brine, and LCS are summarized in Tables 4.4 through 4.6.

Table 4.3 Treatment log for salt brine and LCS applications during the field study.

Data		Chemicals			
		Salt Brine		Liquid Corn Salt (LCS)	
Date	Roadway section	18 miles on Hwy 275 (36 lane-miles)		24 miles on Hwy 81 (96 lane-miles)	
Jan 15	Application period	From	11:00 AM	From	9:00 AM
		To	11:15 PM	To	4:30 PM
		Duration (hr)	12.25	Duration (hr)	7.5
	Applied chemical (gal)	4,500		6,400	
Jan 16	Application period	From	4:15 AM	From	4:50 AM
		To	5:45 PM	To	4:30 PM
		Duration (hr)	13.5	Duration (hr)	11.67
	Applied chemical (gal)	6,000		10,200	
Jan 17	Application period	From	8:00 AM	From	9:00 AM
		To	2:30 PM	To	3:25 PM
		Duration (hr)	6.5	Duration (hr)	6.42
	Applied chemical (gal)	0		1,900[1]	
Jan 18	Application period	From	7:30 AM	From	8:35 AM
		To	9:45 AM	To	12:30 PM
		Duration (hr)	2.25	Duration (hr)	3.92
	Applied chemical (gal)	5,000		3,400[1]	
Total amount (gal)		15,500		21,900	
Total application time (hr)		34.5		29.51	
Effective amount[2] (gal)		15,500		16,600	
Effective application[2] time (hr)		34.5		19.17	
Snow-affected period, if no treatment were applied		From	Jan 15, 08:54 AM	From	Jan 15, 08:54 AM
		To	Jan 19, 10:54 AM	To	Jan 19, 10:54 AM
		Duration (hr)	98	Duration (hr)	98
Cleared period due to treatment		From	Jan 18, 09:45 AM	From	Jan 16, 04:30 PM
		To	Jan 19, 10:54 AM	To	Jan 19, 10:54 AM
		Duration (hr)	25.15	Duration (hr)	66.40

[1] *Amount applied to clean pavement.*

[2] *Application needed to achieve clean pavement*

Table 4.4 Benefit-Cost Worksheet for Salt Brine

Experiment Section Length: 18 miles (Hwy 275)
Safety Improvement Description:

1. Costs

a) Materials

Materials	Unit Price		Amount			Material Cost
Salt Brine	$ 0.05	per gallon	15,500	gallon	=	775

b) Equipments

Equipments	Unit Price	Number of Equipments	Hours		Equipments Cost
Spreader	$ 26.49	1	34.5	=	913.91

c) Personnel

Personnel	Per Person Hour	Number of Person	Hours		Personnel Cost
Operator	$ 28.14	1	34.5	=	970.83

d) Total Costs = (1a)+(1b)+(1c) = 2659.74

2. Benefits

Travel Time Reduction

a) Section Length	18	mile
b) Snow Affected Duration	98	hr
c) Benefitial Period	25.15	hr
d) Posted Speed	60	mph
e) Speed Reduction Rate Due to Snow and Ice	17	%

(Data from Snow Removel and Ice Control Technology, TRB, page 143)

f) ADT of January	3655	veh
g) Truck Percentage	8	%

Vehicle Type	Passenger Car	Single Unit Truck	Tractor-Trailer Truck
f) Volume	3363	146	146
g) Saved Travel Time = (2a)(2c)(2e)(2f) / [24*(2d)(1-(2e))]	216.52	9.41	9.41
h) Values of Time	$ 11.1 /hr	$ 20.4 /hr	$ 23.32 /hr
i) Saved Travel Costs	2403.35	192.04	219.53

j) Total, B = 2814.92

3. Benefit Cost Ratio, B/C = B/K = 1.06

4. Net Benefit = B - K = 155.19

Table 4.5 Benefit-Cost Worksheet for Liquid Corn Salt

Experiment Section Length: 24 miles (Hwy 81)

Safety Improvement Description:

1. Costs

a) Materials

Materials	Unit Price		Amount			Material Cost
Salt Brine	$ 0.2	per gallon	21,900	gallon	=	4,380

b) Equipments

Equipments	Unit Price	Number of Equipments	Hours		Equipments Cost
Spreader	$ 26.49	1	29.51	=	781.72

c) Personnel

Personnel	Per Person Hour	Number of Person	Hours		Personnel Cost
Operator	$ 28.14	1	29.51	=	830.41

d) Total Costs = (1a)+(1b)+(1c) = 5992.13

2. Benefits

Travel Time Reduction

a) Section Length	24	mile
b) Snow Affected Duration	98	hrs
c) Benefitial Period	66.4	hrs
d) Posted Speed	60	mph
e) Speed Reduction Rate Due to Snow and Ice	17	%
(Data from Snow Removel and Ice Control Technology, TRB, page 143)		
f) ADT of January	5561	veh
g) Truck Percentage	8	%

Vehicle Type	Passenger Car	Single Unit Truck	Tractor-Trailer Truck
f) Volume	5116	222	222
g) Saved Travel Time = (2a)(2c)(2e)(2f) /[24*(2d)(1-(2e))]	1159.65	50.42	50.42
h) Values of Time	$ 11.1 /hr	$ 20.4 /hr	$ 23.32 /hr
i) Saved Travel Costs	12872.16	1028.56	1175.79

j) Total, B = 15076.51

3. Benefit Cost Ratio, B/C = B/K = 2.52

4. Net Benefit = B - K = 9084.38

Table 4.6 Benefit-Cost Worksheet for Liquid Corn Salt (Excluding the Last Two Day's Treatment)

Experiment Section Length: 24 miles (Hwy 81)
Safety Improvement Description:

1. Costs

a) Materials

Materials	Unit Price		Amount			Material Cost
Salt Brine	$ 0.2	per gallon	16,600	gallon	=	3,320

b) Equipments

Equipments	Unit Price	Number of Equipments	Hours		Equipments Cost
Spreader	$ 26.49	1	19.17	=	507.81

c) Personnel

Personnel	Per Person Hour	Number of Person	Hours		Personnel Cost
Operator	$ 28.14	1	19.17	=	539.44

d) Total Costs = (1a)+(1b)+(1c) = 4367.26

2. Benefits

Travel Time Reduction

a) Section Length	24	mile
b) Snow Affected Duration	98	hrs
c) Benefitial Period	66.4	hrs
d) Posted Speed	60	mph
e) Speed Reduction Rate Due to Snow and Ice	17	%
(Data from Snow Removel and Ice Control Technology, TRB, page 143)		
f) ADT of January	5561	veh
g) Truck Percentage	8	%

Vehicle Type	Passenger Car	Single Unit Truck	Tractor-Trailer Truck
f) Volume	5116	222	222
g) Saved Travel Time = (2a)(2c)(2e)(2f) /[24*(2d)(1-(2e))]	1159.65	50.42	50.42
h) Values of Time	$ 11.1 /hr	$ 20.4 /hr	$ 23.32 /hr
i) Saved Travel Costs	12872.16	1028.56	1175.79

j) Total, B = 15076.51

3. Benefit Cost Ratio, B/C = B/K = 3.45

4. Net Benefit = B - K = 10709.25

In the benefit-cost worksheets, data used in the 'Costs' part was obtained from maintenance logs. Information for the 'benefits' portion of the benefit-cost worksheets was retrieved from other sources including the meteorology record from NOAA, National Climatic Data Center, average daily traffic data from "2002 Continuous Traffic Count Data and Traffic Characteristics on Nebraska Streets and Highways". Item 2b) in the worksheet, called "Snow Affected Duration", was estimated as the period in which snow and ice would melt themselves without any treatment. In this case, the "Snow Affected Duration" was 98 hours (i.e., the entire study period) since the temperature had been below 32^{o}F from the morning of the Jan 15th to the morning of Jan 19th. "Beneficial period" refers to the time range when the pavement was completely cleaned as the result of chemical application. The beneficial period of salt brine treatment was about 25 hours since the experiment area was not completely cleaned until the beginning of the fourth day, Jan 18th. Regarding LCS, it was mentioned in the log that the second day's goal of application was "Bare or Wet Pavement". Although the result was not specified, the amount of LCS used on Jan 17th was significantly reduced comparing to Jan 16th (from 10,200 gallon to 1,900 gallon). It is apparent that good result had been achieved after the application on Jan 16th. Therefore, the beneficial period of LCS application was 66 hours, from the time when application was finished on Jan 16th to the morning of Jan 19th, when the temperature rose above freezing point.

Assuming that the reduction in travel speed on snow and ice-covered roadways is 17 percent of the posted speed, treatment with salt brine resulted in a benefit/cost ratio of 1.06. It would suggest that this treatment option was just slightly cost-effective under the circumstances of the field study. However, note that the calculated benefit/cost ratio is based on operational benefits (i.e., travel time savings) only. It does not consider the safety benefits associated with reduced accident potentials due to ice- and snow removal.

The conservative estimate of the benefit-cost ratio for LCS is 2.52 as shown in Table 4.5. This value was calculated based on the assumption that the LCS treatment applied to the already clean pavement during the last two days of the study period was necessary. Considering only the effective amount of LCS (i.e., the amount needed to achieve bare pavement), the benefit-cost ratio for LCS is 3.45 as indicated in Table 4.6.

Bare pavement was achieved much sooner on Highway 81 treated with LCS than on Highway 275 treated with salt brine. Therefore, it is expected that safety benefits associated with accident reduction would significantly increase the cost-effectiveness of LCS.

Also, there are other benefits associated with the use of liquid corn salt instead of salt brine. Liquid corn salt is a corn-based product having natural corrosion inhibitor. The use of liquid corn salt can reduce the corrosion to concrete pavement and vehicles as well. Therefore, additional benefits may come from savings in pavement maintenance and from slower vehicle depreciation.

Chapter 5

GENERALIZATION OF RESULTS AND APPLICATION GUIDELINES

5.1 Generalization of Results

Results of the benefit-cost analysis described above correspond to the traffic, roadway and weather conditions observed during a single snow event on two specific highway sections in the Norfolk area. Also, the assumption of vehicles reducing their speed on snow and ice-covered road surfaces at an average rate of 17 percent may not be valid in many cases.

To generalize the results of our study, cost-benefit analyses were performed for a range of ADTs (500-7000 veh/day), truck percentages (5%, 20%, 35%, 50), and two different speed reduction scenarios (10% and 20%) using the snow event of our field study. The benefit-cost ratios for salt-brine and LCS are plotted in Figures 5.1 and 5.2, respectively.

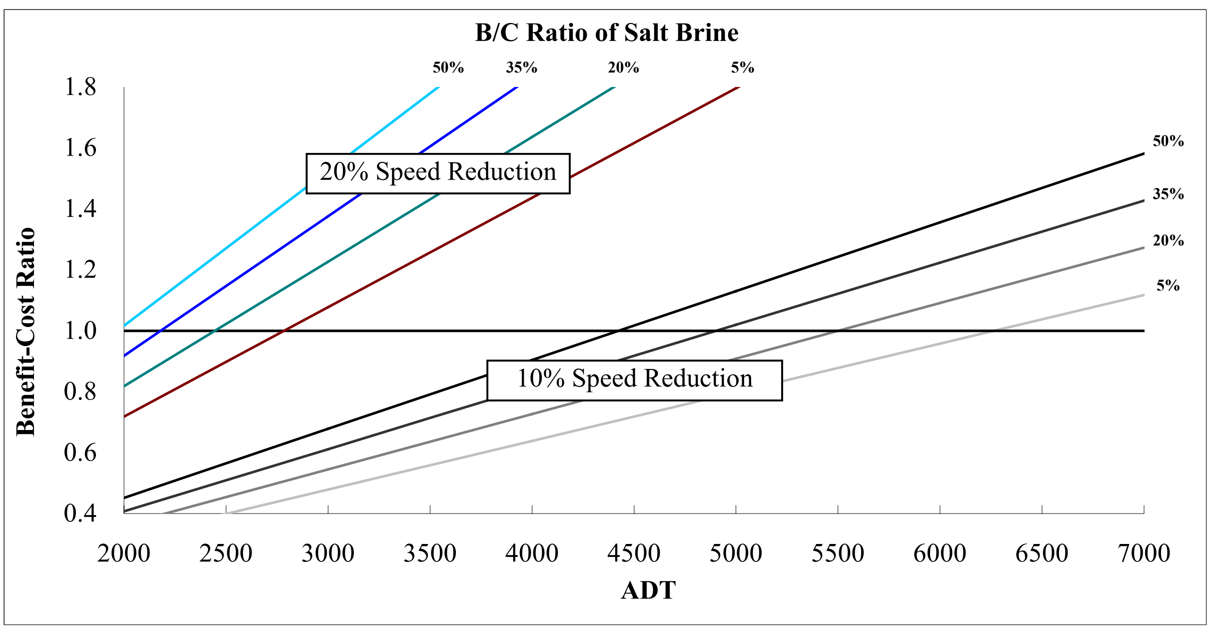


Figure 5.1 Benefit-Cost Ratios For Salt Brine Under Various Traffic Conditions

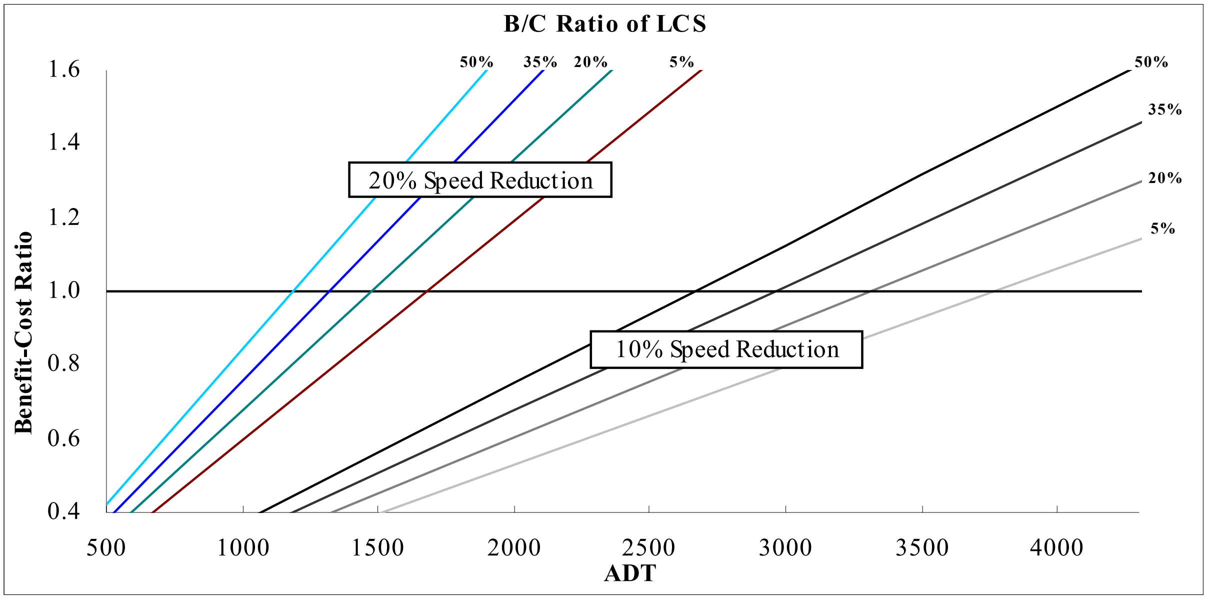


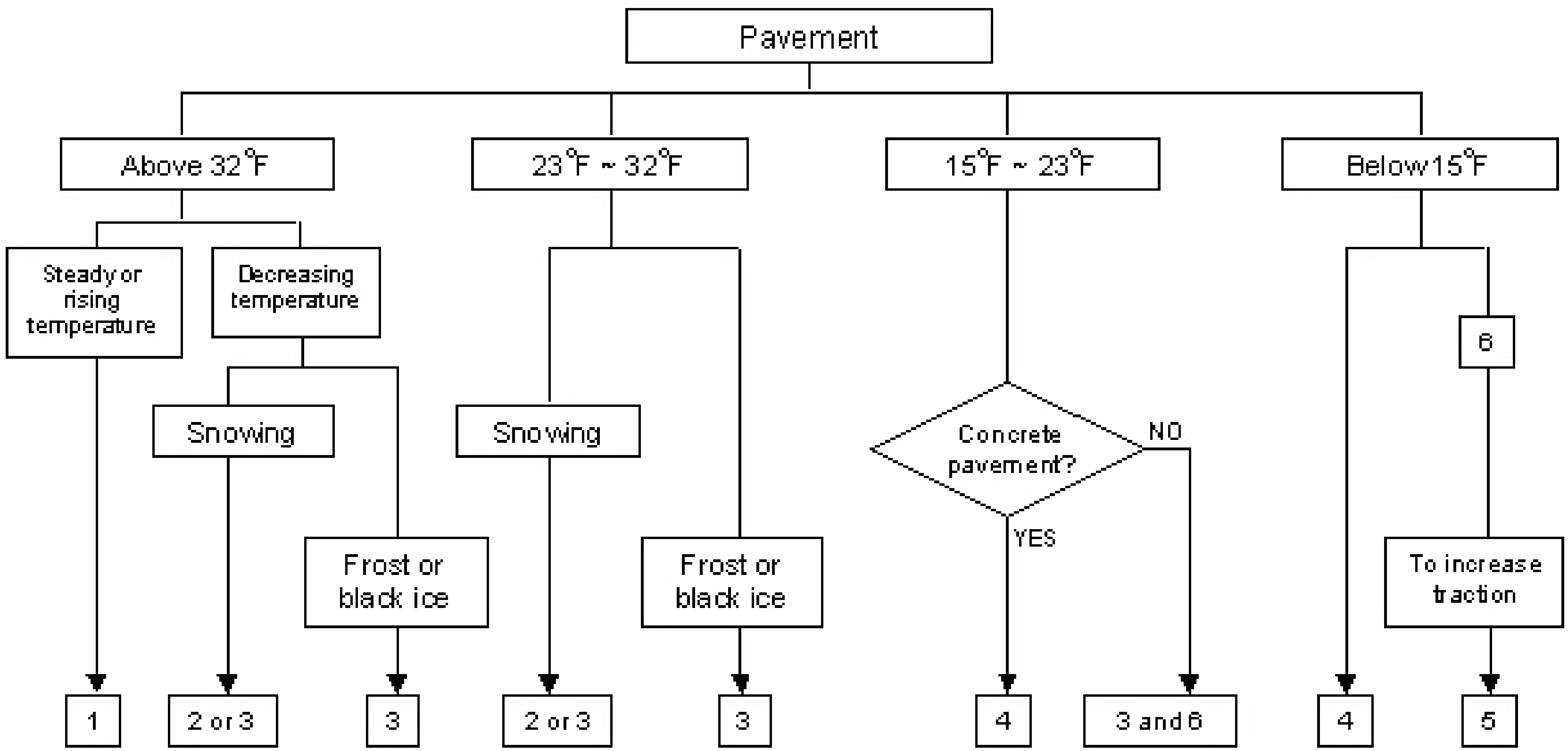
Figure 5.2 Benefit-Cost Ratios For LCS Under Various Traffic Conditions

The choice of maintenance methods can be determined based on the ratio of benefits, resulting from snow and ice removal, to associated costs. For given roadway and traffic conditions, chemicals with higher benefit-cost ratios are given more consideration.

5.2 Guidelines

Based on results of the present study, and findings of previous research, guidelines for the application of some common treatment alternatives were developed. The proposed guidelines are presented in a decision tree format in Figure 5.3. Input to the guidelines includes pavement temperature ranges, temperature trends (i.e., rising, steady, or decreasing), pavement type (i.e., concrete or asphalt), snowfall, and indication of frost or black ice.

These guidelines can be used in combination with Figures 5.1 and 5.2 to account for various traffic conditions (i.e., ADT and truck percentage), and driver behavior (i.e., different degrees of speed reduction in response to icy or snow-covered road surface).



Application alternatives:

1: No application;

2: Liquid salt; any kind of solution of salt that is available (e.g., sodium chloride, calcium chloride, or magnesium chloride)

3: Prewetted solid salt; any kind of salt in solid form and prewetted with either water or a salt solution;

4: Liquid Corn Salt (LCS);

5: Abrasives to enhance traction; normally, prewetted with calcium chloride solution or mixed with solid sodium chloride to prevent caking.

6: Plow.

FIGURE 5.3 Application Guidelines

For example, consider the following problem. The pavement temperature on a roadway section with concrete pavement is in the range of 15-23 ^{o}F at the beginning of a snow event. The average daily traffic is estimated as 3500 vehicles/day of which approximately 20% is truck traffic. It is assumed that drivers in the area typically reduce their speed by about 10% when traveling on snow-covered roadway.

According to Figure 5.3 the recommended treatment option under the given weather and roadway conditions (i.e., temperature is in the range of 15-23 ^{o}F, and pavement material is concrete) would be LCS. Using Figure 5.2 the expected benefit/cost ratio for 3500 vehicles/hour and 20% truck (considering only operational benefits) would be greater than 1, and therefore the application of LCS is cost-effective. However, for a vehicle composition of 5% truck and 95% passenger cars, the B/C ratio would be less than 1 indicating that the treatment would not be cost-effective. However, it should be noted that the expected safety benefits resulting from reduced accident potentials due to snow and ice-removal were not considered here.

Chapter 6

SUMMARY AND CONCLUSIONS

A survey was conducted to review current winter maintenance practice in Nebraska. The survey revealed that there are significant differences in the materials used by various districts in their winter operations. While abrasives are extensively used by almost all districts, there are major differences in their chemical usage for either anti-icing or deicing. District 3 conducted a series of field studies to evaluate the effectiveness of some promising chemicals. Two liquid chemicals, salt brine (i.e., solutions of sodium chloride) and liquid corn salt were considered. These two materials were field tested to evaluate their cost-effectiveness, and to develop guidelines for their most appropriate use.

The field studies were conducted on two highway sections near Norfolk, Nebraska. Because of the fairly mild weather conditions during the winter of 2002-03, there were very few events with significant snow accumulation. From these events, there was only one occasion when the two roadway sections were simultaneously treated with different materials. Highway 275 was treated with salt brine, and Highway 81 with LCS. Available field data included weather information, chemical use, time to achieve bare pavement, and maintenance log records. A benefit-cost analysis was performed to determine the cost-effectiveness of each treatment alternative. The operational benefits were the savings in road user costs resulting from reduction in travel time and delay. They were determined from field study data. The safety benefits related to accident reduction due to improved road surface conditions were not considered because of lack of accident data on LCS-treated roadways. The costs included material, labor and equipment costs. The cost-effectiveness of salt brine and LCS were compared based on their benefit-cost ratios. LCS was found to be more cost-effective than salt brine. Bare pavement was achieved much sooner on Highway 81 treated with LCS than on Highway 275 treated with salt brine. Therefore, it is expected that safety benefits associated with accident reduction would further increase the cost-effectiveness of LCS.

Also, there are other benefits associated with the use of liquid corn salt instead of salt brine. Liquid corn salt is a corn-based product having natural corrosion inhibitor. The use of liquid corn salt can reduce the corrosion to concrete pavement and vehicles as well. Therefore, additional benefits may come from savings in pavement maintenance and from slower vehicle depreciation.

To generalize the results of our study, cost-benefit analyses were performed for a range of ADTs (500-7000 veh/day), truck percentages (5%, 20%, 35%, 50), and two different speed reduction scenarios (10% and 20%) using the snow event of our field study. Although LCS was found more cost-effective during our filed studies, salt brine may be a better choice for different temperature ranges and roadway conditions. Therefore, based on the results of this study and findings of previous research, guidelines were recommended for the most appropriate use of these chemicals and other alternative treatment options for various weather and traffic conditions.

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Appendix A

WINTER OPERATION INFORMATION QUESTIONNAIRE

1. NDOR district:________________
   Name:______________________ Radio Call No.________________

2. Roads in your maintenance area:
   Urban Streets: __________lane-miles;
   Rural Highways: __________lane-miles;
   Interstate Highways: __________lane-miles;
   Expressways: __________lane-miles.

3. What policy or guidelines do you follow for winter operations?
   ____
   ____

4. Describe any potential environmentally sensitive sites (e.g., river, lake) in your district:
   ____
   ____

5. Please indicate the extent to which you used each of the following snow and ice control practices

	Used Extensively	Used Moderately	Used Minimally	Not Used At All
Road check				
Plowing and abrasives				
Anti-icing (chemicals to *prevent* ice bonding to pavement)				
Deicing (chemicals to *break* ice bond to pavement)				

Part 1: Solid chemical application for deicing

(1) What kind of salt do you use?

- ❑ Solid sodium chloride (A)
- ❑ Solid calcium chloride (B)
- ❑ Mixture of A and B
- ❑ Other, please specify:_________

Indicate quantity relative to aggregates (ratio of sand/gravel/salt mixture used)

Are historical data available for tons of salt used?

Estimate the percentage loss of salt due to outside storage:______%

Part 2: Liquid chemical application

(1) In what temperature range will you choose application of liquid chemicals?

____

(2) Which of the following chemicals do you use?

- ❑ Sodium chloride (NaCl)
- ❑ Magnesium chloride ($MgCl_2$)
- ❑ Calcium chloride ($CaCl_2$)
- ❑ Liquid corn salt (LCS)
- ❑ Caliber products (e.g., M1000)
- ❑ Potassium acetate (KAC)
- ❑ Other, please specify:_____________

Part 3: Prewetted Solid chemical application

(1) Which kind of prewetting solution do you use:

- ❑ Sodium chloride (NaCl, salt brine)
- ❑ Calcium chloride ($CaCl_2$)
- ❑ Magnesium chloride ($MgCl_2$)
- ❑ Potassium acetate (KAc)
- ❑ Liquid corn salt (LCS)
- ❑ Caliber products (e.g., M2000)
- ❑ Other, please specify:_____________

Part 4: Decision-making

(1) How often do you use National Weather Service as information source?

____

____

(2) How often do you use Road Weather Information System (RWIS)?

____

____

(3) How often do you get weather information from other sources? Specify sources?

____

____

____

(4) What of the following are considered in your decision-making?

- ❑ Weather forecast information;
- ❑ Short-term forecast based on real-time data;
- ❑ Precipitation;
- ❑ Road conditions;
- ❑ Traffic information;
- ❑ Road checking;
- ❑ Evaluations of treatment effectiveness
- ❑ Other, please specify:____________

(5) Which of the following information can you get for anti-icing?

- ❑ Time when precipitation is expected to start in your region;
- ❑ Duration of precipitation;
- ❑ Form of precipitation;
- ❑ Rate of precipitation;
- ❑ Predicted air temperature during and after the storm;
- ❑ Visibility;
- ❑ Wind direction and speed;
- ❑ Other, please specify:____________

(6) Please circle the pavement information you use from RWIS or other sources:

- ❑ Pavement temperature
- ❑ Pavement condition (wet or dry);
- ❑ Concentration of chemicals left on the pavement;
- ❑ Other, specify:____________

(7) What kind of traffic information do you have for making operational decisions (e.g., local events, commuting traffic)?____

____

____

(8) Please describe if there are post-storm and post-season evaluations of the treatment effectiveness:____

____

Which of the following information does you district maintain?

- ❑ Record of maintenance activity, chemical and equipment use
- ❑ Costs of labor, material, equipments, etc.
- ❑ Traffic and accident data
- ❑ Snow log
- ❑ Diary

Appendix B

Abstracts of Selected Relevant Literature

Publication	Author	Abstract
Ice Control Technology with 20 Percent Brine on Highways, Transportation Research Record 1741, pp. 54-59	Jens Kr. Fonnesbech.	Saturated brine (20 percent) is used for ice clearing to decrease the use of salt (NaCl) but at the same time maintain or increase the level of drivability and safety. A new technique makes it possible to spread brine from a truck traveling 70 km/h (45 mph) in one lane onto the neighboring lanes. The possibility of decreasing the use of salt by changing the spreading method was studied. In Funen County, 20 percent saturated brine has been used successfully to combat icy roads with frost, ice formation on wet lanes, glaze, and snow. In winter 1998-1999, the residual salt from the spreading of brine and prewet salt was measured in 1,800 places. Results showed that saturated brine is spread more evenly across the road than prewet salt, and more salt from the brine is still present on the road 2 h after spreading as compared with prewet salt. Several statistical analyses were carried out, giving a useful picture of the amount of residual salt on the roadway and indicating that more salt from brine than from prewet salt is active on the roadway and that degradation of residual salt is crucially affected by high traffic intensity .In practice, spreading of saturated brine takes effect immediately if there is frost or ice on the road, whereas dry or prewet salt takes time to become effective. Likewise, it has been shown in practice that saturated brine is effective in glaze and snow conditions, but 20 mL (4.6 g/m^2 NaCl) normally is not enough. Use of saturated brine has produced such good results that within the next 10 years Funen County is expected to convert to the sole use of this method of ice clearing. The most common application is expected to be 20 mL/m^2 or less, but in special cases it might be necessary to use 40 mL/m^2.
Assessment of the Performance of Prewetted Salt for Snow Removal and Ice Control. Transportation Research Record 1741, pp. 68-74	Marilyn Burtwell.	In the United Kingdom, the primary method of preventing ice from forming on road surfaces is to spread rock salt with purpose-built spreaders that regulate both the rate of spread and the spread pattern. British Standards Institution Standard BS3247 requires that the rock salt contain no more than 4 percent moisture by weight. Although salt is an effective deicing chemical, its extensive and intensive use on roads has been found to corrode vehicles, damage highway structures, cause detrimental effects to vegetation, and increase groundwater pollution. Prewetted salt is under trial on minor roads by local authorities in England and Scotland. The U .K. Highways Agency commissioned TRL Limited to review the use and to determine the potential benefits of prewetted salt. The use of prewetted salt has been compared with the use of dry rock salt in terms of their environmental effects as well as their cost. Factors such as salt loss due to trafficking and climatic conditions, potential hazards and damage to structures, and safety issues arising from the use of prewetted salt have been investigated. Field trials are in progress in the winter of 2000-2001 to determine the efficacy of prewetted salt as a precautionary treatment.

		The trials will be used to assess specifications for materials and equipment, the cost and method of retrofitting brine tanks to a spreader, the accuracy of spread width and pattern, and salt residue on the road and verge. The final results of this study will enable the Highways Agency and local authorities to determine whether to introduce prewetted salt on U.K. roads and, if so, the climatic conditions under which it should be used.
Winter Friction Project in Norway. Transportation Research Record 1741, pp. 34-41	Jon Dahlen and Torgeir Vaa.	The Winter Friction Project in Norway deals with practical, technical, and economic problems arising in providing good friction on winter roads. One of the main activities throughout the whole project period will be to carry out field studies, which will consist of (*a*) a testing program (scientific studies) to document performance of different friction improvement methods and (*b*) a follow-up study on roads in 10 counties to document existing winter maintenance practice on both salted and sanded roads. Scientific studies during the 1998-1999 winter season revealed that new measures carried out with sanding methods last longer than do traditional sanding methods. Although the effect of using cold and dry sand can disappear after the passage of 50 vehicles, it has been proved that by using heated materials or adding warm water to the sand it is possible to maintain a friction level above the standard, even after the passage of 2,000 vehicles. In particular, a method using a mix of hot water and sand showed promising results. During summer and autumn 1999, the warm-wetted sanding method was further improved by development of two new Norwegian prototypes. These new spreaders have been tested together with alternative ways of adding water (type of spreader and temperature of the water). Wet sand has been compared with traditional sanding using dry materials. The field tests carried out during the winter season 1999- 2000 with wet sand and roller distributor confirm the results from last season. Good results were achieved with the Norwegian trucks.
Life Cycle Cost-Benefit Model for Road Weather Information Systems. Transportation Research Record 1627, pp. 41-48	Benjamin McKeever, Carl Haas, Jose Weissmann, and Rich Greer.	To ensure safer driving conditions on highways, state highway agencies are exploring the use of new technologies that will improve the flow of information about hazardous road conditions. These technologies are called Road Weather Information Systems (RWIS). The objective of this paper is to provide a systematic methodology for highway agencies to evaluate the costs and benefits associated with implementing RWIS. This objective was achieved through the development of a life cycle cost-benefit model for RWIS. This analysis tool provides highway agency decision makers with a methodology through which different RWIS implementation alternatives can be evaluated from economic, qualitative, and environmental perspectives. A case study demonstrating the use of the RWIS cost-benefit model also is included. The purpose of the case study is to evaluate whether or not it is cost-beneficial to implement an RWIS on Interstate 20 near Abilene, Texas. The model determined that it was cost-beneficial to implement this system.
A Manual on User Benefit Analysis of Highway and	American Association of State Highway and	This manual provides cost factors, nomographs, and guidelines for estimating the economic effects of highway and bus-transit improvements on highway and transit

Bus-Transit Improvements	Transportation Officials, Washington, D.C. 1997	users. It is intended to replace the 1960 AASHTO report "Road User Benefit Analyses for Highway Improvements." The manual presents all of the information needed for economic analysis of most types of highway and bus-transit improvements, including curve elimination, widening or adding lanes, reducing gradients, new road construction, intersection controls, dedication of lanes for buses, and changes in bus routes or schedules. However, the manual user must first supply physical and financial data on the improvement and estimate its effect on highway capacity and traffic, transit patronage, miles of bus travel, and average bus service speed.
Highway Deicing: Comparing Salt and Calcium Magnesium Acetate. Transportation Research Board. Special Report 235. National Research Council. Washington, D.C. 1991.		Each year about $1.5 billion is spent on highway snow- and ice- control programs in the United States. Apart from plowing, the most important element of these programs is chemical deicing, which represents about one-third of winter maintenance expenditures. Chemical deicing provides important public mobility and safety benefits by rapidly and reliably providing more drivable and less hazardous road conditions during the winter months. The benefits are difficult to quantify but are widely acknowledged to be valuable to society. Sodium chloride, or common road salt, is by far the most popular chemical deicer, because it is reliable, inexpensive, and easy to handle, store, and apply. Since 1970, highway agencies have applied an average of approximately 10 million tons of road salt each winter. Over the years, however, the widespread use of salt has been linked with many indirect costs, including damage to motor vehicles, infrastructure, and the environment. Recognizing these drawbacks, in 1980 the Federal Highway Administration identified calcium magnesium acetate (CMA) as a possible replacement for salt. Since its discovery, CMA has been the subject of many laboratory and field studies to determine its deicing performance, environmental acceptability, and compatibility with automotive and highway materials. Results have been promising, but the most significant impediment to its use has been its price, which is more than 20 times that of salt. The commercial availability of CMA and continued concerns about the indirect costs of salting have underscored the need for more information on the total cost of deicing. Recognizing this need, in 1988 Congress requested a study comparing the true costs of salt and CMA, including direct application costs and indirect costs to the environment, human health, motor vehicles, and infrastructure. A special committee of the Transportation Research Board carried out the study. The committee focused most of its efforts on determining the true cost of salting, which was last estimated 15 years ago for the Environmental Protection Agency. In addition, the committee reviewed what is known about CMA as a deicer and identified major cost and use issues that need to be addressed when CMA is considered as a replacement for salt.